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GB 2311697 A GB 2310974 A GB 2291300 A
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(54) Abstract Title
Mobile station location

(57) A mobile station (MS) location algorithm stores and extends multiple paths, each thereof having a finite probability of defining the preceding locations of the MS. The said probability is quantified by a path probability metric, resulting from a product calculation, the multiplicand thereof being the prior path probability metric which was associated with the path before the path was extended, and the multiplier thereof being the probability that the MS is located at the end point of the extended path while giving no consideration to the history of MS movement. A MS location is independently predicted using an autoregressive process applied in turn to orthogonal co-ordinates of the locations which form the path having the highest path probability metric at that instant. The path probability metrics associated with all paths are modified according to the relative position of the predicted location to the path end points.

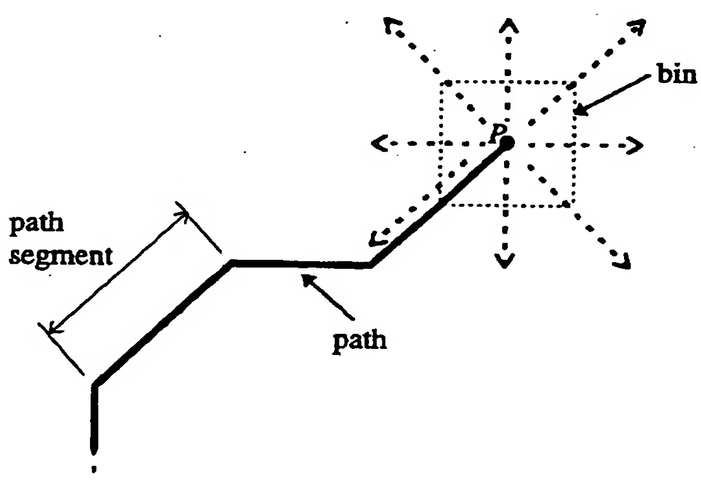

Figure 2

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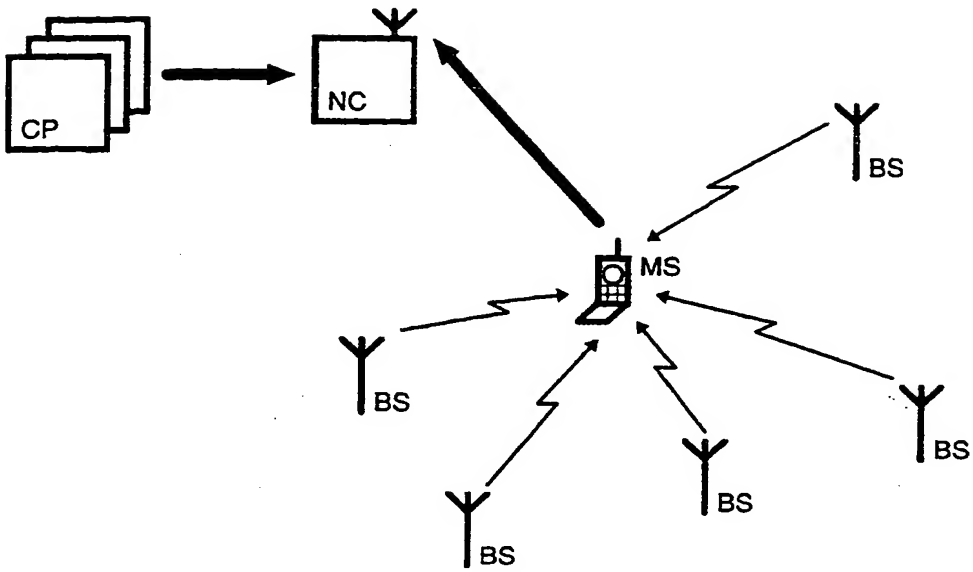

Figure 1

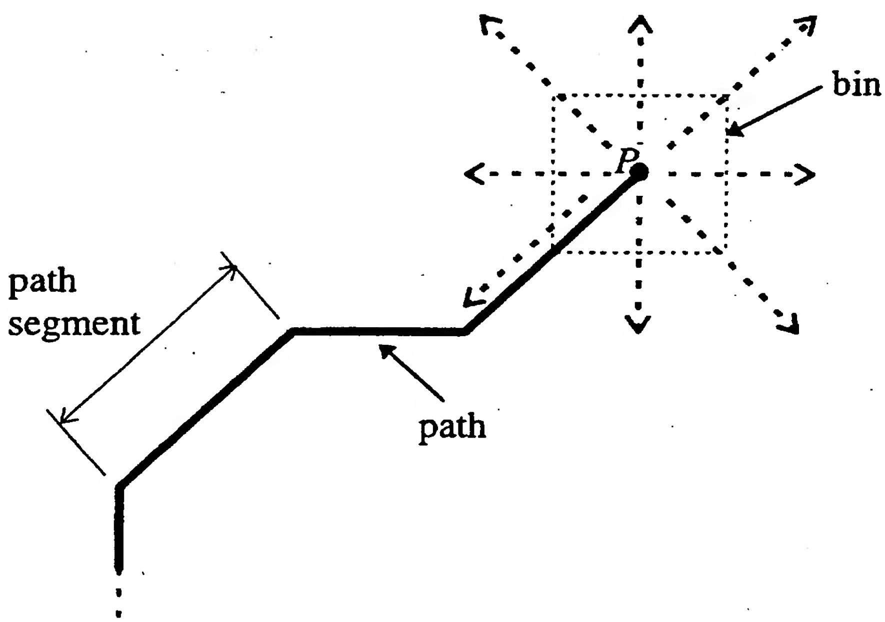

Figure 2

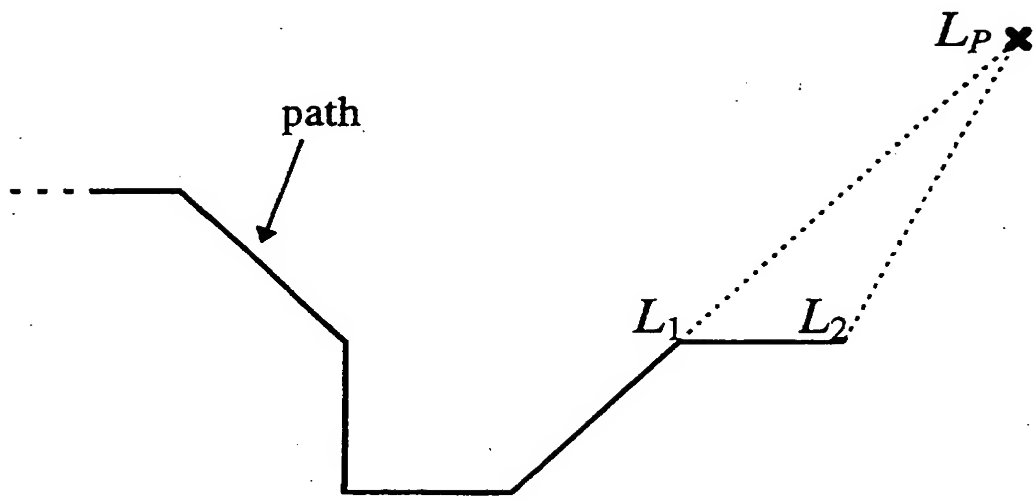

Figure 3

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Mobile Station Location

This invention relates to the location of mobile stations (MSs) in communication systems and particularly, but not exclusively, in cellular telecommunication systems.

Cellular telecommunication networks are characterised by a plurality of base stations (BSs), each of which communicates, as required, via a radio link to the MSs located within their radio coverage area. BSs are linked to a hierarchical control means which, for the purpose of this invention, we group together under the term network controller.

It is beneficial to establish the precise location of a MS, both for internal management of network resources and for the commercial exploitation of location based services (eg in-car route finder applications). At the first level, the identity of a BS currently engaged in transmission with a MS may be used to locate the MS given an *a priori* knowledge of the coverage area of the BS.

To locate a MS with greater precision requires the use of additional location specific information. Many digital cellular systems specify that a MS should measure the received signal strength of transmissions from a plurality of surrounding BSs, and subsequently report these measurements back to the network controller. Using a radio propagation model, the network controller may be given *a priori* knowledge of the expected received signal strength at each location and from each BS, hereafter referred to as the coverage prediction from each BS. Hence, by comparison of the measurement reports of received signal strength with the coverage prediction, an estimate of probable MS locations can be obtained. Indeed, by applying the probability density function of errors exhibited by the radio propagation model, a quantified probability metric may be calculated for every location for which coverage predictions are provided, where a high metric infers that there is a reasonable probability that the MS is situated at that location, and a low metric infers that there is only a small chance that the MS is situated at that location. Accordingly, the location with the highest metric is deemed to be the best estimate of the MS location by the network controller. All probability metrics may be recalculated at subsequent time

increments, during which time the MS may have moved. Substantial errors inherent to the propagation model render a large margin of uncertainty in the location estimate.

Summaries of the Invention

According to one aspect of the invention there is provided an algorithm in the network controller comprising (1) probability metric calculation means, the calculation being performed in successive time increments for the then current set of a MS's measurement reports and for one possible location, but repeated for many possible locations, and (2) path storage means, a path being a unique set of adjacent locations that has a finite probability of defining the preceding locations of the MS, the probability thereof being quantified by a path probability metric resulting from a product calculation, the multiplicand thereof being the prior path probability metric which was associated with the path before the path was extended, and the multiplier thereof being the probability that the MS is located at the end-point of the extended path while giving no consideration to the history of MS movement, the said path storage means containing a plurality of such paths each thereof extended and updated at successive time increments, a path being removed from the path storage means only at such time as the associated path probability metric falls below a certain threshold.

Thus, the estimate of MS location is determined by a probability metric that is accumulated over all prior time increments rather than being based on the current input only. The effect is to reduce the margin of uncertainty in the location estimate.

According to a second aspect of the invention there is provided an algorithm in the network controller comprising (1) probability metric calculation means, the calculation being performed in successive time increments for the then current set of a MS's measurement reports and for one possible location, but repeated for many possible locations, (2) path storage means, a path being a unique set of adjacent locations that has a finite probability of defining the preceding locations of the MS, the probability thereof being quantified by a path probability metric resulting from a product calculation, the multiplicand thereof being the prior path probability metric which was associated with the path before the path was extended, and the multiplier thereof being the probability that the MS is located at the end-point of the extended

path while giving no consideration to the history of MS movement, the said path storage means containing a plurality of such paths each thereof extended and updated at successive time increments, a path being removed from the path storage means only at such time as the associated path probability metric falls below a certain threshold, and (3) means for independently predicting the current MS location, the location prediction being based on the path with the highest path probability metric from the preceding time increment, and being used to modify the probability metrics of all said stored paths in the current time increment.

By these means, a location is independently predicted and, for each stored path, the position of the path relative to the predicted location is used to determine a bias to the path probability metric. The effect is to exploit the spatial correlation of natural MS movement and hence further decrease the uncertainty in the MS location estimate.

Description of Preferred Embodiment

A specific embodiment of the invention will now be described, by way of example only, with reference to the accompanying drawings in which:

Figure 1 is a schematic overview of the MS location system,

Figure 2 illustrates a single stored path being extended to locations adjacent to the original path end-point, *P*, and

Figure 3 is a schematic view of a single stored path, showing the location used in the biasing of path probability metrics by linear prediction.

The invention relates to an algorithm implemented in a network controller and used to track individual MSs as they move about within a cellular radio telecommunications network. Referring to Figure 1, it is assumed that the MS measures the received signal strength from surrounding BSs and reports this information to the network controller (NC). The network controller has access to coverage predictions (CP) for each BS, with which it may compare the reported signal strength values. The algorithm used to locate the MS has three main facets: calculation of the *static probability* that a MS exists in an area referred to as a bin residing at a particular location (or bin), the

application of *temporal information* to increase the certainty of MS location, and the addition of *linear prediction* to exploit the tendency of a MS to move in predictable ways.

Static Probability

For a given set of reported signal strengths at an instant, we seek to determine the probability that a MS is at particular locations. For an isolated BS, the predicted signal strength at the location of interest, defined by co-ordinates (x, y), is $P_{x,y}$. The reported signal strength from the MS that is not actually at (x, y) but at location (a, b) is P_R. The probability, $D_{x,y}$, that the search point (x, y) is identical to the MS location (a, b) depends on the difference between the predicted and measured signal strength and the probability distribution function of errors in the prediction model. We assume that prediction errors are normally distributed with zero mean and standard deviation σ. Therefore, we have,

$$D_{x,y} = g\{\delta\}, \qquad (1)$$

where

$$\delta = P_{x,y} - P_R, \qquad (2)$$

and

$$g\{\delta\} = \frac{1}{\sqrt{2\pi\sigma^2}} \cdot e^{\frac{\delta^2}{2\sigma^2}}. \qquad (3)$$

A similar probability may be calculated for each BS reported by the MS. The probability of the MS being at location (x, y) given reports on K BSs is

$$D_{x,y} = \prod_{i=1}^{K} \left(D_{x,y}\right)_i = \prod_{i=1}^{K} g\left\{\left(P_{x,y}\right)_i - \left(P_R\right)_i\right\}. \qquad (4)$$

Temporal Information

The unit of time used in the algorithm is referred to as a *time increment*. The time increment is chosen such that the MS is unable to move more than one bin in one increment. The first time increment, eg, following the establishment of a call, is a

special case. The static probability is calculated for every bin within the coverage area of the cell handling the communications and known here as the serving cell. All probabilities are ranked in order and all but the top N are discarded. A typical value for N is 100. By asserting that the MS is contained within one of the N bins, we may scale each probability to form a probability metric such that the total probability metric is unity. Each of these bins forms the seed of a *path* which extends at each time increment of the algorithm.

A standard iteration of the algorithm receives as an input N paths, generated in the previous iteration and each having an associated path probability metric. The algorithm is best described as a stepped process.

Step 1: Taking each path in turn, as illustrated in Figure 2, the static probability is calculated in each bin adjacent to the path end-point, P, ie, using Equation 4 for values of x and y which deviate by ±1 from the co-ordinates of P.

Step 2: The static probability is multiplied by the existing path probability metric which was passed into this time increment of the algorithm from the previous time increment. The single path has now branched into nine paths each with a unique path probability metric.

Step 3: A number of paths will have collided. Of the paths which converge at a particular bin, all but the one with the highest probability are discarded, and the survivor is given a new probability metric equal to the sum of the metrics of all the paths which converged there.

Step 4: The paths are ranked in order of probability metric.

Step 5: The most probable location for the MS is at the end of the path with the highest probability metric. This is the output of the algorithm for the current time increment.

Step 6: The top N paths are stored ready for the next time increment and the rest are discarded.

Step 7: To ensure that the probability metrics do not become smaller with each time increment, the MS is assumed to be at one of the end points of the stored paths. The probability metric of each path is scaled to ensure that the total probability metric of all paths is one.

Linear Prediction

The algorithm described above does not consider the orientation of paths, eg, a path that follows a straight line is not thought of as being more likely than one that meanders from side to side, even though the latter violates our intuitive expectation of MS movement. The second aspect of the invention seeks to redress this using linear prediction of the next MS location given the locations in the most likely path. As an example, a standard fifth order autoregressive process is used on the x and y co-ordinates independently. The predicted location is passed into each iteration of the algorithm (together with the N stored paths) and is used to modify the probability metric of each new path as it is generated. Two additional steps are inserted between Step 2 and Step 3 of the above process as follows.

Step 2a For each generated path, a multiplying factor, G, is formulated which is dependent on the relative position of the predicted location to the end of the path currently under consideration. As an example, one approach would be to implement the following criteria.

1. The metrics of paths moving towards the predicted location are increased.
2. The metrics of paths moving away from the predicted location are decreased.
3. The magnitude of the increase or decrease is greater for paths which terminate close to the predicted location.

Figure 3 schematically represents one potential path, under consideration in the algorithm, selected from the many paths which exist at each time increment. The location of the end-point of the path

is L_2, and L_1 marks the preceding location along the same path, ie the end point in the preceding time increment. The predicted location is represented by the cross marked L_P.

With reference to Figure 3, a suitable mathematical expression to express the above criteria is

$$G = \left(\frac{\|L_1 - L_P\|}{\|L_2 - L_P\|} \right)^q , \qquad (5)$$

where the difference terms imply Euclidean distance calculations, and the parameter, q, may be used to modify the intensity of the change in the path probability.

Step 2b Multiply the probability of each generated path by the factor, G.

Claims

1. A mobile station (MS) location means comprising the storage of a plurality of potential paths, each thereof having an associated probability metric accumulated over prior time increments.

2. A MS location means as claimed in Claim 1 wherein the said path probability metrics result from a product calculation in which the multiplicand thereof is the prior path probability metric which was associated with the path before the path was extended, and the multiplier thereof is the probability that the MS is located at the end-point of the extended path while giving no consideration to the history of MS movement

3. A MS location means as claimed in Claim 1 wherein the said potential paths are discarded, having no further effect on the MS location means, if their said path probability metric falls below a certain threshold.

4. A MS location means as claimed in Claim 3 wherein the threshold is determined by the path probability metric of a path holding a pre-determined position in an ordered list of stored paths, in descending order of path probability metric.

5. A MS location means as claimed in Claim 1 wherein the subsequent MS location is independently predicted and used to modify the path probability metrics of stored paths.

6. A MS location means as claimed in Claim 5 wherein the said predicted MS location is determined by an auto-regressive process applied in turn to orthogonal co-ordinates of the locations which form the path having the highest said path probability metric at that instant.

7. A MS location means as claimed in Claim 5 or Claim 6 wherein the said predicted location is used to modify the said path probability metrics by increasing the metrics of paths which are extended towards the said predicted location, and by decreasing the metrics of paths which are extended away from the said predicted location.

8. A MS location means as claimed in Claim 5 or Claim 6 or Claim 7 wherein the severity of the said modification to the said path probability metrics is determined by the Euclidean distance from the path end-point to the said predicted location.

9. A MS location means substantially as described herein with reference to Figures 1-3 of the accompanying drawings.

Amendm nts to th claims hav b n fil d as follows

1. A mobile station (MS) location means comprising the storage of and selection from a plurality of potential paths, each being extended at constant time intervals, and each having an associated probability metric accumulated over prior time intervals, wherein the said path probability metrics result from a product calculation in which the multiplicand thereof is the prior path probability metric which was associated with the path before the path was extended, and the multiplier thereof is the probability that the MS is located at the end-point of the extended path while giving no consideration to the history of MS movement.

2. A MS location means as claimed in Claim 1 wherein the subsequent MS location is independently predicted and used to modify the path probability metrics of stored paths.

3. A MS location means as claimed in Claim 2 wherein the said predicted MS location is determined by an auto-regressive process applied in turn to orthogonal co-ordinates of the locations which form the path having the highest said path probability metric at that instant.

4. A MS location means as claimed in Claim 2 or Claim 3 wherein the said predicted location is used to modify the said path probability metrics by increasing the metrics of paths which are extended towards the said predicted location, and by decreasing the metrics of paths which are extended away from the said predicted location.

5. A MS location means as claimed in Claim 2 or Claim 3 or Claim 4 wherein the severity of the said modification to the said path probability metrics is determined by the Euclidean distance from the path end-point to the said predicted location.

6. A MS location means substantially as described herein with reference to Figures 1-3 of the accompanying drawings.

Application No:	GB 9801256.0	**Examiner:**	Glyn Hughes
Claims searched:	1 to 9	**Date of search:**	21 July 1998

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.P): H4D (DAB, DLAB, DLSX, DLPG, DLPX, DPBC, DPBX, DPX, DSPL, DSPJ, DSPV, DSPX), H4L (LDSL)

Int Cl (Ed.6): G01S 1/02, 1/04, 5/14, H04Q 7/38

Other: Online: WPI

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
X	GB 2311697 A	(MATSUSHITA) see abstract	1
X	GB 2310974 A	(PHONELINK) see whole document	1, 3
X	GB 2291300 A	(MOTOROLA) see abstract	1, 3
X	EP 0631453 A2	(TELIA AB) see whole document	1

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Y Document indicating lack of inventive step if combined with one or more other documents of same category.
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